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Students: ZEBULON MARTIN, Otterbein University, JAMES BUSCH, Washington & Lee University, SHANNON DILLON, Colgate University, SARAH HOLMES, Beloit College, GABRIELA GARCIA, Oberlin College, SARAH BENDER, The College of Wooster, ERIN PEELING, Pennsylvania State University, GREGORY MAK, Trinity University, THOMAS HEROLD, The College of Wooster, ADELE IRWIN, Washington & Lee University, ILLIAN DECORTE, Macalester College

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JAMES BUSCH, Washington & Lee University
Research Advisor: Lisa Greer, Washington & Lee University

INTRODUCTION

In recent decades Caribbean coral reefs have experienced significant decline in live coral cover. In particular, scleractinian corals have been hardest hit of the hexacorallia in the Caribbean. The main framework-building corals, *Acropora* species, have dominated Caribbean reefs through geologic time, but have experienced massive population decline and mortality since the 1980's (Aronson and Precht, 2001; Greenstein et al., 1998). The drastic decline of *Acropora* spp. throughout the Caribbean led to *Acropora cervicornis* and *Acropora palmata* becoming the first two coral species listed as threatened under the Endangered Species Act in 2005 by NOAA's National Marine Fisheries Service. There are few remaining places where *Acropora* spp. corals are abundant and healthy (Lirman et al., 2010; Keck et al., 2005).

The recent decline of *Acropora* spp. corals is particularly important to understand because in addition to being significant Caribbean reef framework builders, *Acropora* spp. are unique because of their structural complexity and high growth rates making them ecologically very important for Caribbean and Western Atlantic ecosystems (Williams and Miller, 2012).

Recent field studies by project contributors suggest that Coral Gardens, Belize represents one of the few remaining locations in the Caribbean with abundant, healthy populations of *Acropora* spp. coral. Anecdotal reports suggest *Acropora* spp. corals have been well established at Coral Gardens in the past, but it is unclear what their past extent has been. A comprehensive literature search suggests that there

have been no long term studies of *Acropora* spp. corals at Coral Gardens, and thus there is no available data about their abundance, extent, or persistence through time. Due to this lack of information, it is difficult to ascertain whether the populations of *Acropora* spp. coral have experienced recent decline. In light of this, an efficient and reliable method is required to identify *Acropora* spp. corals for studying, protection, and long term monitoring.

The purpose of this study was to document *Acropora* spp. coral cover and extent near Coral Gardens using GeoEye-1 imagery, devise a classification methodology for identifying *Acropora* spp. corals from other benthic cover that is user friendly, time efficient, and inexpensive, create an exportable product identifying *Acropora* spp. populations near Coral Gardens that other people can utilize in field studies, and use the mapped *Acropora* spp. populations to design a Marine Protected Area at Coral Gardens.

METHODS

Initial Image Classification

GeoEye-1 multispectral satellite imagery of a 25 km² area near Ambergris Caye was analyzed to identify the live *Acropora* coral cover in the greater Coral Gardens region. The GeoEye-1 imagery has a spatial resolution of 0.46 m, three visible light bands (450-690 μm), and one near IR band (780-920 μm). A supervised classification was used to separate *Acropora* spp. from other benthic cover such as mixed sand, sea grass, macroalgae, and other mixed coral species. To characterize the spectral character of *Acropora* spp. cover, a previously mapped refuge of live *Acropora*

spp. coral located in the northern part of Coral Gardens was used for the classification "training areas." Ten point features were then placed within the largest identified regions of suspected live *Acropora* spp. coral on the classified image.

The accuracy of the supervised classification was tested in the field using snorkelers to ground-truth the ten point features. At each point features they made observations about live coral cover, depth, orientation of live coral, species of corals present, and height of the tallest live coral. Locations were recorded using a Trimble GeoExplorer XT 6000 differential GPS for smaller areas of live *Acropora* spp. corals with an accompanying estimate of area coverage, and perimeters were mapped for larger stands of live coral. Additionally, reference locations of other benthic cover such as sand and sea grass were also recorded to help refine the method of spectrally distinguishing live *Acropora* spp. corals from other benthic cover. The GPS data was post processed using Pathfinder Office software, and the differential correction was performed using a reference base station in Quintana Roo, Mexico.

Refined Image Classification

Following the accuracy assessment of the supervised classification map in the field, the classification scheme was refined to improve the accuracy of identifying *Acropora* spp. corals from other benthic cover. *Acropora* spp. coral, sea grass *(Thalassia testudinum* and *Syringodium filiforme)*, and other massive coral species such as *Montastrea* spp. were identified as the most important benthic units for refining the classification scheme. The spectral signature of each benthic unit was extracted from the image, compared, and examined at their most representative "reference areas." Although the three benthic units are spectrally similar, there is a clear inverse relationship between the red Band 3 (655-690 μm) and the blue Band 1 (450-510 μm) for the *Acropora* spp. benthic unit. This inverse relationship was then used as an impetus to carry out a Band 3 to Band 1 ratio. An unsupervised classification was performed on the Band 3/Band 1 ratio image, and

the class which only populated the *Acropora* spp. reference areas was isolated and displayed to yield the distribution map of *Acropora* spp. corals.

To quantitatively assess the accuracy of the initial supervised classification and refined classification methods, reference points and underwater photography from the field were used to map areas in which there was exclusively one of the types of benthic units (*Acropora* spp. coral, dense sea grass, or mixed massive corals). For *Acropora* spp. coral, the survey transects were used as reference areas because the amount of live *A. cervicornis* coral was already quantified along the transects using 1 m^2 quadrats and underwater photography. In each mapped reference area, it was assumed that 100% of the area was comprised of its respective benthic cover, and the area of classified *Acropora* spp. was calculated as a percentage of the total area. The proportion of classified *Acropora* spp. coral in the *Acropora* spp. reference area was used to calculate the amount of false negatives, and the proportion of classified *Acropora* spp. in the mixed massive coral and dense sea grass reference areas was used to calculate the amount of false positives for the initial supervised classification and refined classification methods.

A proposed Marine Protected Area was then drawn around the extent of the mapped *Acropora* spp. corals, which were generally located in stands very closely to one another. The extent of the MPA was strategically chosen after an extensive literature search on ideal sizes and designs for MPA's.

Within the proposed MPA, a full characterization of the benthic cover was carried out by combining the initial supervised classification of *Acropora* spp. corals, the Band 3/Band 1 ratio unsupervised classification of *Acropora* spp. corals, and an additional supervised classification which used the reference points as training areas for clean sand, mixed turtle grass, sand, and rubble, light turtle grass and sand, medium turtle grass, and dense turtle grass. The area of each benthic unit was then calculated as a percentage of the total area of the MPA.
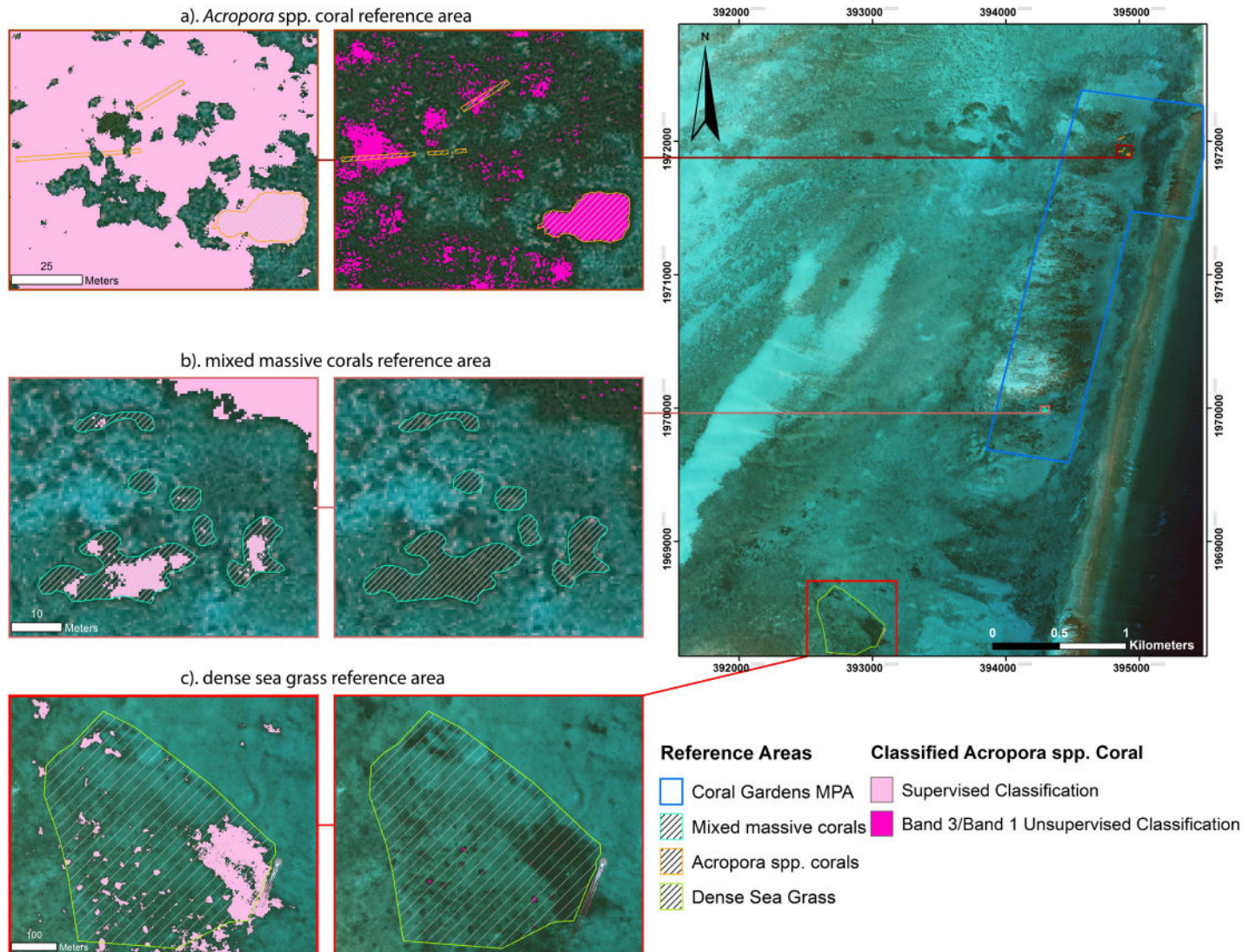
RESULTS

Figure 1. A comparison between the initial supervised classification and the Band 3/Band 1 ratio unsupervised classification of identified Acropora spp. corals at each reference area.

A comparison between the initial supervised classification and the unsupervised classification of the Band 3/Band 1 ratio qualitatively shows that the accuracy of identifying *Acropora* spp. coral from other benthic units increased with the refined classification methodology (Figure 1).

The fully characterized seafloor of the Coral Gardens MPA indicates how the ideal habitat for both *Acropora* spp. corals and other massive corals populates a relatively thin but long stretch of the back reef and lagoonal area (Figure 2).

A summary of the observations and GPS data collected during the field assessment (Table 1) shows how there

is both a significant amount of *Acropora* spp. coral and diversity of corals present in an area approximately 3 kilometers long. The most abundant benthic unit in the Coral Gardens MPA is light sea grass and sand, and *Acropora* spp. coral is about one fifth as abundant as all other mixed coral species (Table 2).

The results of the accuracy assessment for the two classification methods identifying *Acropora* spp (Table 3) show how the supervised classification technique identified benthic cover more broadly, with lots of false positives but few false negatives, and the refined classification technique was more selective, with fewer false positives but more false negatives. From
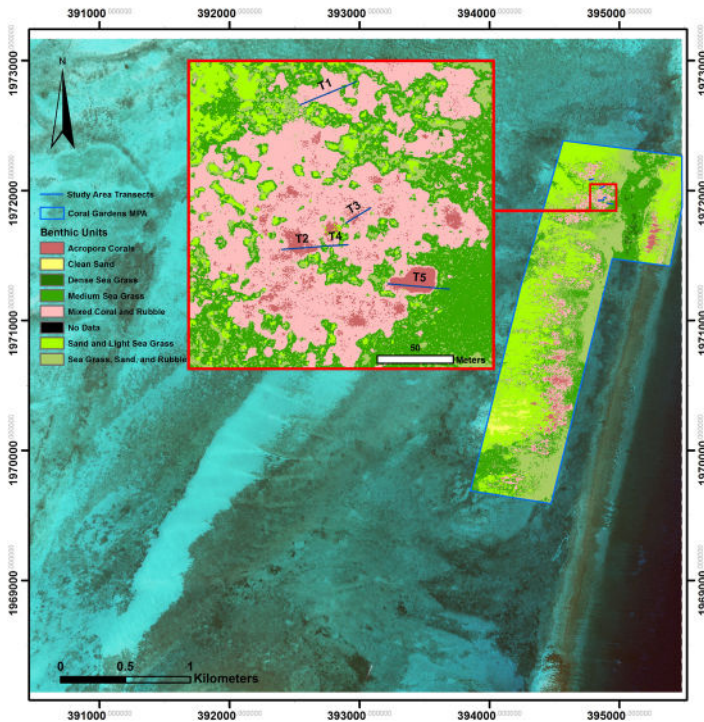
Figure 2. The proposed Coral Gardens Marine Protected Area with the benthic cover fully characterized.

the initial to refined classification, there was a 39.88% decrease in false positives and a 23.25% increase in false negatives.

DISCUSSION

Imagery Classification Techniques

The results from the field assessment found that the initial supervised classification method was successful in identifying populations of *Acropora* spp. coral, but a significant amount of dense grass and mixed massive coral was mis-classified as *Acropora* spp. coral (Table 3).

The refined classification method that used an unsupervised classification of the Band 3/Band 1 ratio resulted in a significant decrease in the number of false positive classifications of sea grass, dense sea grass, and mixed massive coral (Table 3). The most significant decreases in false positive identification were for dense sea grass, which decreased by 13.45%,

Table 1	
GPS points	29
GPS perimeters	9
Newly documented *A. cervicornis* stands	22
Newly documented *A. palmata* stands	5
Newly documented *A. prolifera* stands	4

Table 2	
Benthic unit	% area in CG MPA
No Data	0.01
Acropora spp. Coral	2.23
Mixed Massive Corals	10.48
Clean Sand	1.33
Sea Grass, Sand, and Rubble	29.4
Light Sea Grass and Sand	31.98
Medium Sea Grass	23.96
Dense Sea Grass	0.62
Total area of CG MPA (km^2)	2.08

Table 1. A summary of the observations and GPS data collected in the field while testing the accuracy of the initial supervised classification.

Table 2. The percentage of each benthic unit of the total Coral Gardens MPA area.

Table 3

Benthic unit	Area (m^2)	Initial supervised classification (%)	Bands 3:1 unsupervised classification (%)
Acropora spp. coral	549	97.40	74.15
dense sea grass	172,172	13.60	0.15
mixed massive coral	410	26.43	0.00

Table 3. A summary of the accuracy assessment for the classification of Acropora spp. corals for the initial supervised classification and the Band 3/Band 1 ratio unsupervised classification.

and mixed massive coral, which decreased by 26.43%. It is quite remarkable that for the mixed massive coral reference area (Fig. 2), the unsupervised classification of the Band 3/Band 1 ratio did not identify any *Acropora* spp. coral, which leads to the conclusion that the methodology successfully separates *Acropora* spp. coral from other coral types.

The results also show an increase in the number of false negatives for the refined classification method; however, this may also be a reflection of the inaccuracy of the null hypothesis for the *Acropora* spp. reference area, which was that 100% of the area is live coral cover. Although the reference areas are along transects with lots of live *Acropora* spp. coral, only a percentage of the coral cover is actually alive, and it was found from the transect surveys that the highest live coral cover for a transect was 50.27% (Erin Peeling, this volume). In fact, Transect 1 had only 14.28% live coral cover, which one would actually expect to result in less classified live *Acropora* spp. cover. Therefore, the increase in false negatives for the refined classification method may actually be a more accurate reflection of the amount of live *Acropora* spp. cover, but it would extremely difficult to assess the accuracy of the classification at such a fine scale.

Considering the success of the initial supervised classification, as judged from the ground truthing, the improved accuracy of the refined classification method proves to be a successful means for identifying populations of *Acropora* spp. corals in a GeoEye-1 image and discerning them from other types of benthic cover, including other types of corals. The method is also relatively easy to employ, inexpensive, and can be utilized by other researchers conducting similar field studies and planning Marine Protected Areas for at-risk localities.

The main drawback to the classification technique is that the location of at least one population of *Acropora* spp. corals has to be known within the image in order to identify which "class" contains the identified *Acropora* spp. coral. An automated methodology which identifies populations of *Acropora* spp. coral for the researcher is the ultimate goal, and image texture analysis paired with the use of the infrared spectral band was explored to try and achieve this goal. Although unsuccessful, there is much potential for further research on image texture analysis applications to identifying *Acropora* spp. coral in satellite imagery because of their intermediate to shallow depth regime, as well as their unique branching morphology. These unique characteristics of *Acorpora* spp. corals could be captured in imagery that has both higher spectral and spatial resolution than GeoEye-1, such as WorldView-3 imagery.

MPA Planning and Conservation

This study is the first to document the extent of *Acropora* spp. corals in Coral Gardens, which is important when considering the creation of a Marine Protected Area in the Coral Gardens area. MPA's have been shown to improve density, biomass, organism size, and species richness of communities within reserve boundaries following implementation in high risk areas (Lester et al., 2009). MPA's have become increasingly popular as an efficient and inexpensive way to maintain and manage fisheries, as well as preserve biodiversity in areas that are particularly prone to damage from anthropogenic factors (Halpern, 2003). At Coral Gardens, both goals could be achieved given the high abundance of *Acropora* spp. coral and their unique branching framework, which provides much of the fish's habitat on Caribbean reefs.

Two important considerations when planning MPA's are their size and connectivity to other MPA's. The literature suggested that when considering the sustainability of fisheries, which are closely tied to coral reef health in the Caribbean, that MPA's should be large enough so that populations within reserves can sustain themselves, but still small enough so that some larvae produced inside the MPA can be

transported to unprotected areas (Almany et al., 2007). The extent of the Coral Gardens MPA was chosen to include all regions of identified *Acropora* spp. corals given their threatened status and ecological importance to reef biodiversity. This inclusion made the extent rather large, which would likely cause more resistance from local fisherman; however, when considering connectivity, the Hol Chan MPA is located approximately 0.5 kilometers North of the Coral Gardens MPA and the Caye Caulker MPA is located approximately 1.5 kilometers South of Coral Gardens MPA. The Coral Gardens MPA with its proposed extents would allow excellent connectivity between the Hol Chan and Caye Caulker MPA's, which are currently separated by approximately 3 kilometers of unprotected water that sees heavy boat traffic.

With the addition of the Coral Gardens MPA, the decreased fishing pressure would optimize larval transport, facilitate the growth of fish populations, and promote increased biodiversity within the reserve. It is also likely that with recovering fish populations within the MPA's fishing would improve throughout the area between Amerbergris Caye and Caye Caulker, which would be beneficial to locals dependent on the fisheries. Considering the health of *Acropora* spp. corals, the Coral Gardens MPA would promote their continued health and growth by decreasing fisherman traffic in the area, and assist in keeping Coral Gardens a refuge of *Acropora* spp. corals.

ACKNOLEDGEMENTS

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